

## PROJECT SUMMARIES

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### TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES

Carlos F. Borges, Associate Professor

Department of Applied Mathematics

Sponsor: Unfunded

**OBJECTIVE:** To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

**SUMMARY:** This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. A variety of different approaches have been investigated and some very fast and robust algorithms have been developed for solving the problem for a single Bezier curve. These algorithms have been extended to work with B-spline curves with general knot sequences. This past year a paper was submitted on this work to Computer Aided Geometric Design. The paper has been accepted and should appear in 2002.

#### PUBLICATIONS:

Borges, C.F. and Pastva, T.A., "Total Least Squares Fitting of Bézier and B-Spline Curves to Ordered Data," *Computer Aided Geometric Design*, Vol. 19, No. 4, pp. 275-289, 2002.

**DoD KEY TECHNOLOGY AREA:** Other (Scientific Computation)

**KEYWORDS:** Curve Fitting, Data Compression, Approximation Theory

### RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMMANCHE HELICOPTER

Donald A. Danielson, Professor

Department of Applied Mathematics

Sponsors: Comanche Program Office and Naval Postgraduate School

**OBJECTIVE:** Professor Danielson continued his work in support of ongoing development of the Army's RAH-66 *Comanche* helicopter. Two NPS thesis students supported him. This year he used a finite element code to predict the effects of an explosion inside the forward tailcone of the Comanche.

**SUMMARY:** The model was based on Comanche structural information from engineers Jason Firko and Mel Niederer, located at Boeing helicopters in Philadelphia. The MSC.Software code Patran was used as the pre and post processor, and the MSC.Software code Dytran as the computational engine. The Catia model was not suitable for meshing, but the geometry therein was transferred to a new group and became the basis for the model. With further study of copies of the large engineering drawings, a faithful replica of the Comanche tailcone was constructed. The final geometry consists of 56 surfaces and 10 solids. The tailcone structure is meshed with 25,261 Lagrangian elements (16,665 2-D shell elements plus 8,596 3-D solid elements) of edge length 1 inch. The fluid region is meshed with 22,113 3-D solid Eulerian elements of edge length 2 inches. The model has 5 different 2-D orthotropic materials, which are used to construct the laminate composites for the shell elements. It also uses an aluminum material for some shell elements. The vents' shell elements are modeled with an extremely weak material, so that the inner surface forms a closed volume (required in Dytran). A 3D orthotropic material is assigned to the solid Lagrangian elements. Material properties of air are assigned to the Eulerian elements. Generic (unclassified) initial properties are used for the sphere containing the blast wave. A job was run and graphical results were inserted into the final report.

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### **PUBLICATIONS:**

Danielson, D.A., "Comanche Tailcone Model Documentation," Naval Postgraduate School Report, sent to Boeing, 2001.

### **THESIS DIRECTED:**

Gorak, M. and Libby, J., "Finite Element Modeling of the RAH-66 Comanche Tailcone Section Using Patran and Dytran," Masters Thesis, Naval Postgraduate School, June 2001.

**DoD KEY TECHNOLOGY AREAS:** Air Vehicles, Modeling and Simulation

**KEYWORDS:** Helicopters, Airframes, Explosions, Computer Software

### **EFFICIENT TRAJECTORY OPTIMIZATION**

**Fariba Fahroo, Associate Professor**

**Department of Applied Mathematics**

**Sponsor: Draper Labs**

**OBJECTIVE:** The objectives of this research are to explore spectral patching techniques, their accuracy, and efficiency for solving both continuous and discontinuous trajectory optimization problems.

**SUMMARY:** This research produced a numerical method for solving complex trajectory optimization problems in a rapid manner. The spectral patching method developed advances the state of the art in trajectory optimization by providing solutions that are provably optimal. In this project, the spectral patching method was developed and implemented in MATLAB. A numerical package called DIDO, which was based on the numerical method was developed and a launch problem among other examples from astronautics were solved using the package.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Space Vehicles, Modeling and Simulation

**KEYWORDS:** Spectral Patching Techniques, Trajectory Optimization

### **DEPLETION LENGTHS IN SEMICONDUCTOR NANOSTRUCTURES**

**Chris Frenzen, Associate Professor**

**Department of Applied Mathematics**

**James Luscombe, Professor**

**Department of Physics**

**Sponsor: Unfunded**

**OBJECTIVE:** In this research a formula for the depletion length in a cylindrical nanostructure was developed, and investigated in various asymptotic limits. It was shown that the standard formula for depletion lengths at a planar semiconductor interface underestimates the depletion length in nanostructures of finite radius.

**SUMMARY:** The depletion,  $W(R)$ , at the surface of a cylindrical nanostructure of radius  $R$  is calculated and shown to satisfy a certain inequality which bounds  $W(R)$  below by  $W_p$  and above by  $W_p$  times the square root of two, where  $W_p$  is the depletion length at a planar interface. The standard result  $W_p$  is shown to underestimate the depletion length in a finite structure. The discrepancy between  $W_p$  and  $W(R)$  becomes significant when the dimensions of the structure become comparable to the depletion length, as can occur in nanostructure devices. This work has been accepted for publication in the journal *Solid State* and will appear in 2002.

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### PUBLICATIONS:

Frenzen, C., "Depletion Lengths in Semiconductor Nanostructures," *Solid State Electronics*, Vol. 46, pp. 885-889, 2002.

**DoD KEY TECHNOLOGY AREAS:** Manufacturing Science and Technology (MS&T)

**KEYWORDS:** Semiconductor Nanostructures, Depletion Length

### EFFICIENT NONLINEAR TRANSIENT DYNAMIC ANALYSIS FOR STRUCTURAL OPTIMIZATION USING AN EXACT INTEGRAL EQUATION FORMULATION

**Joshua Gordis, Associate Professor**  
**Department of Mechanical Engineering**  
**Beny Neta, Professor**  
**Department of Applied Mathematics**  
**Sponsor: National Science Foundation**

**OBJECTIVE:** The focus of this phase of the project is the development of an improved solution algorithm for fast transient analysis of large, locally nonlinear structures using time domain structural synthesis.

**SUMMARY:** Time domain structural synthesis is a general and exact formulation for transient problems in structural modification, substructure coupling, and base excitation. The formulation is characterized by the governing equation of the synthesis, which is a nonlinear Volterra integral equation. The governing equation makes use of impulse response functions calculated for those coordinates of the (sub) structures subjected to forces of synthesis (e.g. modification forces, coupling forces). This physical coordinate formulation provides for a largely unrestricted and exact model reduction, in that only those coordinates of interest need be retained in the synthesis. The development of several algorithms intended to improve upon the original algorithm developed by Gordis are documented.

The last algorithm developed meets the stated goals of the project. This algorithm is a newly developed recursive, block-by-block convolution solution to the governing nonlinear integral equation. As is demonstrated with a simple but realistically large nonlinear base excitation problem (51,500 DOF finite element model), the new algorithm provides a 78% reduction in time required for the nonlinear transient base excitation solution, as compared with traditional direct integration calculated using a widely-used commercial finite element program. This very large savings in computer time is obtained for a single analysis, i.e. assuming no prior calculations have been made for the impulse response functions of the (sub) structures. The new algorithm provides an even greater reduction in computer time for all subsequent analyses. As shown in the example problem, once all required impulse response functions have been calculated, the nonlinear base isolation solutions calculated using the new recursive, block-by-block convolution algorithm take approximately 7 seconds, as compared with the direct integration solution, which takes approximately 30 minutes. This rapid reanalysis capability will facilitate the development of numerical optimization for the design of nonlinear isolation.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Modeling and Simulation

**KEYWORDS:** Finite Elements, Structural Synthesis, Convolution, Block-By-Block, Adaptive

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### COORDINATED FORMATION AND ATTITUDE CONTROL OF MULTI-SATELLITE SYSTEMS

Wei Kang, Associate Professor  
Department of Applied Mathematics

Sponsor: Air Force Research Laboratory and Naval Postgraduate School

**OBJECTIVE:** The objectives of the project are (1) design robust feedbacks that meet the needs of attitude control and coordination; (2) identify some attitude stabilization and attitude tracking problems that is useful for satellite formation missions; (3) selection of key parameters to build a perceptive frame; (4) reference projection design, and hybrid control architecture design for the purpose of coordinated control; (5) simulation and lab test of the control design.

**SUMMARY:** The PI visited AFRL on WPAFB three times to collaborate with the AFRL research team in this subject. The design algorithm based on perceptive frame developed in NPS and MSU is combined with an H-infinity optimal attitude controller to coordinate multiple satellites. Two conference papers and a journal paper from this project were published or accepted during October 2000-September 2001. One more journal paper was submitted.

#### PUBLICATIONS:

Kang, W., Xi, N. and Sparks, A., "Theory and Applications of Formation Control in a Perceptive Referenced Frame," *Proceedings IEEE Conference on Decision and Control*, Sydney, Australia, 12-15 December 2000.

Kang, W., Yeh, H.H. and Sparks, A., "Coordinated Control of Relative Attitude for Satellite Formation," *Proceedings AIAA Guidance, Navigation, and Control Conference*, 6-9 August 2001.

Kang, W. and Yeh, H.H., "Coordinated Attitude Control of Multi-Satellite Systems," *International Journal of Robust and Nonlinear Control*, Vol. 12, pp. 185-205, 2002.

Nelson, E., Sparks, A. and Kang, W., "Coordinated Nonlinear Tracking Control for Satellite Formations," *Proceedings AIAA Guidance, Navigation, and Control Conference*, 6-9 August 2001.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Space Vehicles, Modeling and Simulation

**KEYWORDS:** Attitude Control

### VISIBLE SETS AND ITS MANUFACTURING APPLICATIONS

Wei Kang, Associate Professor  
Department of Applied Mathematics

Sponsor: Ford Scientific Research Lab and Naval Postgraduate School

**OBJECTIVE:** The focus of this project for the year of 2001 is on the production planning based on information feedback. Mathematical model of production planning integrating both statistical data and IT based fast information feedback is developed.

**SUMMARY:** An index theory was developed for the proposed problem. It numerically interprets the visibility of each side of a mechanical part. Dynamical programming is applied with the index theory to minimize the number of sensor locations to inspect every surface of a mechanical part. Also funded by Ford Scientific Lab, the Robotics Lab of MSU is building up a system with robot arms, sensors and softwares. The theory developed in this project will be implemented in the lab, and the entire system will be tested using real auto parts from the sponsor.

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### PUBLICATIONS:

Kang, W. and Song, M., "Manufacturing Planning Based on Information Feedback," *Proceedings 6th International Conference on Control, Automation, Robotics and Vision*, Singapore, 5-8 December 2000. (Best Paper Award, 6th International Conference on Control, Automation, Robotics and Vision, Singapore, 5-8 December 2000.)

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Manufacturing Science and Technology (MS&T)

**KEYWORDS:** Production Planning

### GALERKIN SPECTRAL SYNTHESIS METHODS

**Beny Neta, Professor**

**Department of Applied Mathematics**

**Sponsor: Unfunded**

**OBJECTIVE:** To develop existence and uniqueness theory for the energy dependent, steady state neutron diffusion equation with inhomogeneous oblique boundary conditions imposed. Also to develop a convergence theory for the Galerkin Spectral Synthesis Approximations.

**SUMMARY:** An existence and uniqueness theory is developed for the energy dependent, steady state neutron diffusion equation with inhomogeneous oblique boundary conditions imposed. Also, a convergence theory is developed for the Galerkin Spectral Synthesis Approximations which arise when trial functions depending only on energy are utilized. The diffusion coefficient, the total and scattering cross-sectional data are all assumed to be both spatially and energy dependent. Interior interfaces defined by spatial discontinuities in the cross-section data are assumed present. Our estimates are in a Sobolev-type norm, and our results show that the spectral synthesis approximations are optimal in the sense of being of the same order as the error generated by the best approximation to the actual solution from the subspace to which the spectral synthesis approximations belong.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software

**KEYWORDS:** Galerkin, Spectral Synthesis, Diffusion

### ORBIT DETERMINATION

**Beny Neta, Professor**

**Department of Applied Mathematics**

**Sponsor: Unfunded**

**OBJECTIVE:** To develop a method for trajectory propagation that better reflects the energy consumption of the system.

**SUMMARY:** In this work a method was developed for the solution of the equations of motion of an object acted upon by several gravitational masses. In general, the motion can be described by a special class (for which  $y_-$  is missing) of second order initial value problems (IVPs).

$Y'(x) = f(x, y(x)), y(0) = y_0, y'(0) = y'_0.$

The numerical integration methods for this can be divided into two distinct classes:

- (a) problems for which the solution period is known (even approximately) in advance;
- (b) problems for which the period is not known.

Here only some methods of the second class were considered. Numerical methods of Runge-Kutta type as well as linear multi-step methods can be found in the literature. Our idea here is to develop a new method that conserves the energy per unit mass in the case of perturbation-free right and use the energy in

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other cases to approximate the angular variation. The generalization to cases where the energy is not conserved is given. Numerical experiments for both cases were computed and the solution to well established methods was compared.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Space Vehicles, Modeling and Simulation

**KEYWORDS:** Orbit Determination, Numerical Algorithms